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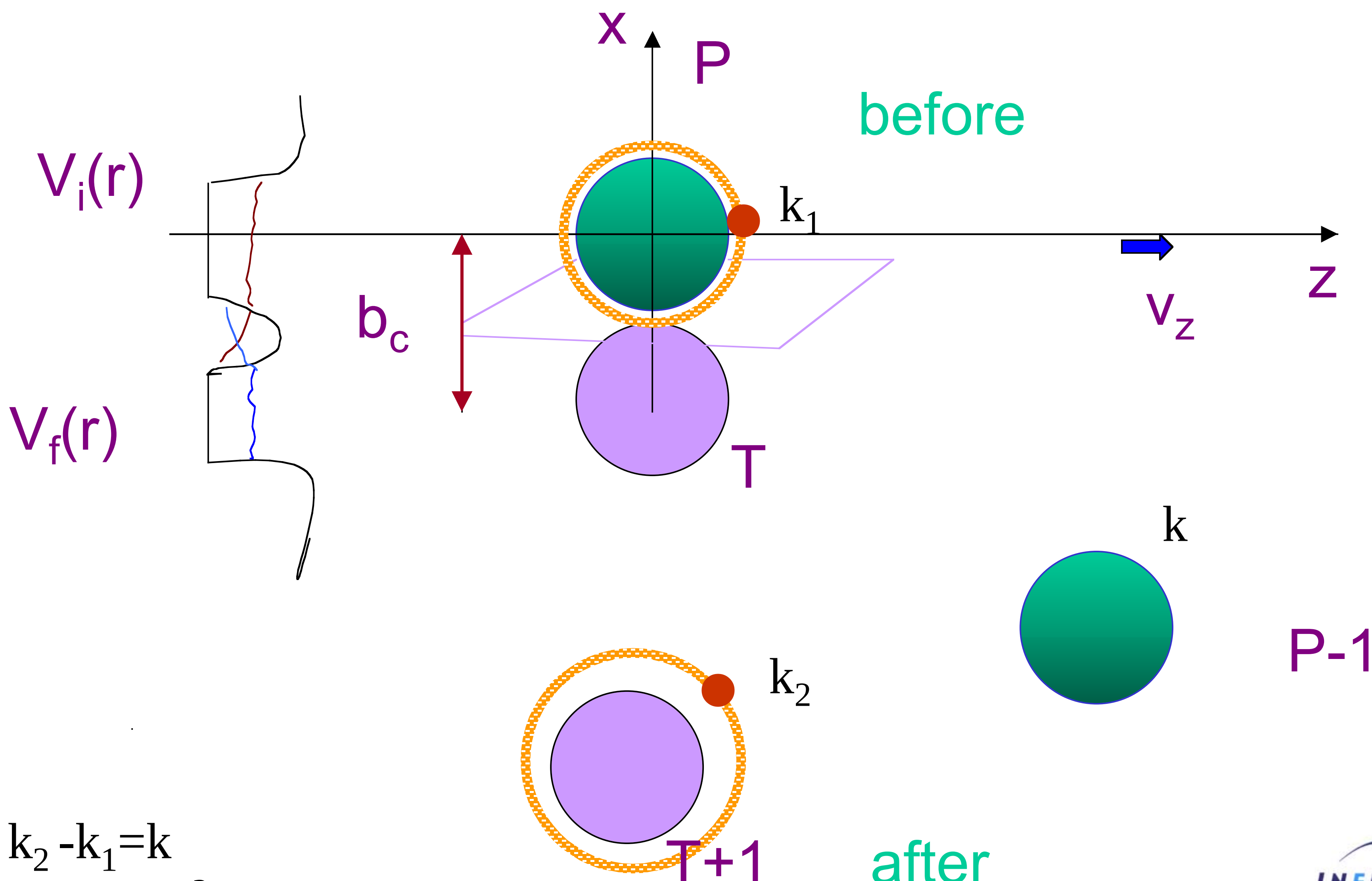
Pisa: Torre Pendente

Transfer to the continuum method

D. M. Brink, G. Blanchon, F. Carstoiu

- (n) or (p) Transfer reactions to unbound states → breakup
  → surrogate to free neutron-T scattering P+T → (P-n) + (T+n)*
  → (P-n) + T+n
- Final state interaction theory (Fermi, Watson…)
- Examples :
  low-lying resonances in ^{209}Pb
  the problem of ^{10}Li ground state → ^{11}Li
- Optical potentials for weakly bound projectiles

Transfer to the continuum dynamics



$k_2 - k_1 = k$

$\varepsilon_f - \varepsilon_i = mv^2/2$

The neutron Schrödinger equation

$$i\hbar\frac{\partial\Phi}{\partial t} = (T + V_1(r_1,t) + V_2(r_2,t) + V_C(r_1, R(t))\Phi(t)$$

$$A_{12} =< \Phi_{2\,out}(t_2)|G_2V_2G_1|\Phi_{1\,in}(t_1)>$$

$$A_{11} =< \Phi_{2\,out}(t_2)|G_1V_2G_1|\Phi_{1\,in}(t_1)>$$

$$A_{01} =< \Phi_{2\,out}(t_2)|G_0V_2G_1|\Phi_{1\,in}(t_1)>$$

Semiclassical treatment of core-target relative motion, BUT full QM treatment of n-target interaction

AB and DM Brink, PRC38, 1776 (1988), PRC43, 299 (1991),PRC44, 1559 (1991).

$$\frac{d\sigma}{d\varepsilon_f} = C^2 S \int_0^\infty d\mathbf{b_c} \; \frac{dP(b_c)}{d\varepsilon_f} \; P_{el}(b_c), \qquad \text{where} \qquad P_{el}(b_c) = |S_{cT}|^2$$

$$A_{if} = \frac{1}{i\hbar} \int \; dt < \psi_f(t) | V(r) | \psi_i(t) >$$

$$V(r) = U(r) + iW(r)$$

Same physical content of DWBA when the semiclassical limit applies:

A study of semi-classical approximations for heavy ion transfer reactions,
H. Hasan and D.M. Brink, J Phys G4, 1573 (1978).
Perturbation approach to nucleon transfer in heavy ion reactions,
L. Lo Monaco and D.M. Brink, J.Phys. G, 935 (1985).

$$\psi_i(r,t) = \phi_i(r) e^{-\frac{i}{\hbar}\varepsilon_i t}$$

$$\psi_f^*(r,t) = \phi_f^*(r) e^{\frac{i}{\hbar}\varepsilon_f t}$$

$$\phi_i(r) = -C_i \gamma_i h_{l_i}^{(+)}(\gamma_i r) Y_{l_i m_i}(\theta,\phi)$$

$$\phi_f(r) = C_f k_f \frac{i}{2}[h_{l_f}^{(+)}(k_f r) - S_{l_f}^* h_{l_f}^{(-)}(k_f r)] Y_{l_f m_f}(\theta,\phi)$$

$$A_{if}(\mathbf{k_f}, b_c) \approx \int dk_y \sqrt{k_y^2 + \eta^2}\, \bar{\phi}_i(d_1, k_y, k_1) \bar{\phi}_f^*(d_2, k_y, k_2)$$

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standing the transfer and breakup mechanisms and the best matching ions

$$\frac{dP_t(b_c)}{d\varepsilon_f} = \frac{1}{8\pi^3}\frac{mk_f}{\hbar^2}\frac{1}{2l_i+1}\Sigma_{m_i}|A_{fi}|^2$$

$$\approx \frac{4\pi}{2k_f^2}\Sigma_{j_f}(2j_f+1)(\underbrace{|1-\bar{S}_{j_f}|^2}_{\text{elastic}}+\underbrace{1-|\bar{S}_{j_f}|^2}_{\text{absorption}})(1+F_{l\to j})B_{l_f,\ldots}$$

$$= \sigma_{nN}(\varepsilon_f)\mathcal{F},$$

enhancement factor of of final state interaction theory

$$B_{l_f,l_i} = \frac{1}{4\pi}\left[\frac{k_f}{mv^2}\right]|C_i|^2\frac{e^{-2\eta b_c}}{2\eta b_c}M_{l_f l_i}$$

angular parts of $\psi_{i,f}$

$k_f \equiv (i\eta, k_z)$

$|\tilde{\psi}_i|^2$ Fourier transform of initial w. f.

$$k_1 = -\frac{\varepsilon_i - \varepsilon_f + \frac{1}{2}mv^2}{\hbar v}$$

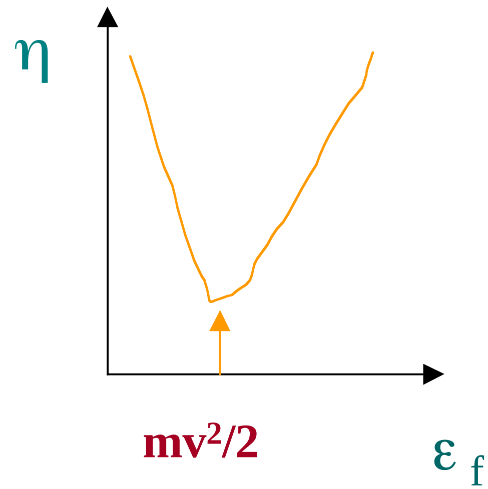
$$k_2 = -\frac{\varepsilon_i - \varepsilon_f - \frac{1}{2}mv^2}{\hbar v}.$$

$$\eta^2 = \gamma_i^2 + k_1^2 = k_2^2 - k_f^2$$

$$\gamma_i^2 = -\frac{2m\varepsilon_i}{\hbar^2}$$

$$k_f^2 = \frac{2m\varepsilon_f}{\hbar^2}$$

$$\mathbf{k_f} \equiv (\mathbf{k}_\perp, k_\mathbf{z}) = (i\eta, k_2)$$



If both initial and final state have l=0

Bound to bound

$$\sigma(\varepsilon_f) = \frac{\pi}{2}|C_i C_f|^2 \left[\frac{\hbar}{mv}\right]^2 \int_0^\infty d\mathbf{b_c} \frac{e^{-2\eta b_c}}{\eta b_c} e^{(-\ln 2 exp[(R_s - b_c)/a])}$$

Bound to continuum

$$\frac{d\sigma}{d\varepsilon_f} = \left(\frac{\sin\delta_0}{k_f}\right)^2 |C_i|^2 \frac{m k_f}{\hbar^2} \left[\frac{\hbar}{mv}\right]^2 \int_0^\infty d\mathbf{b_c} \frac{e^{-2\eta b_c}}{\eta b_c} e^{(-\ln 2 exp[(R_s - b_c)/a])}$$

scattering length

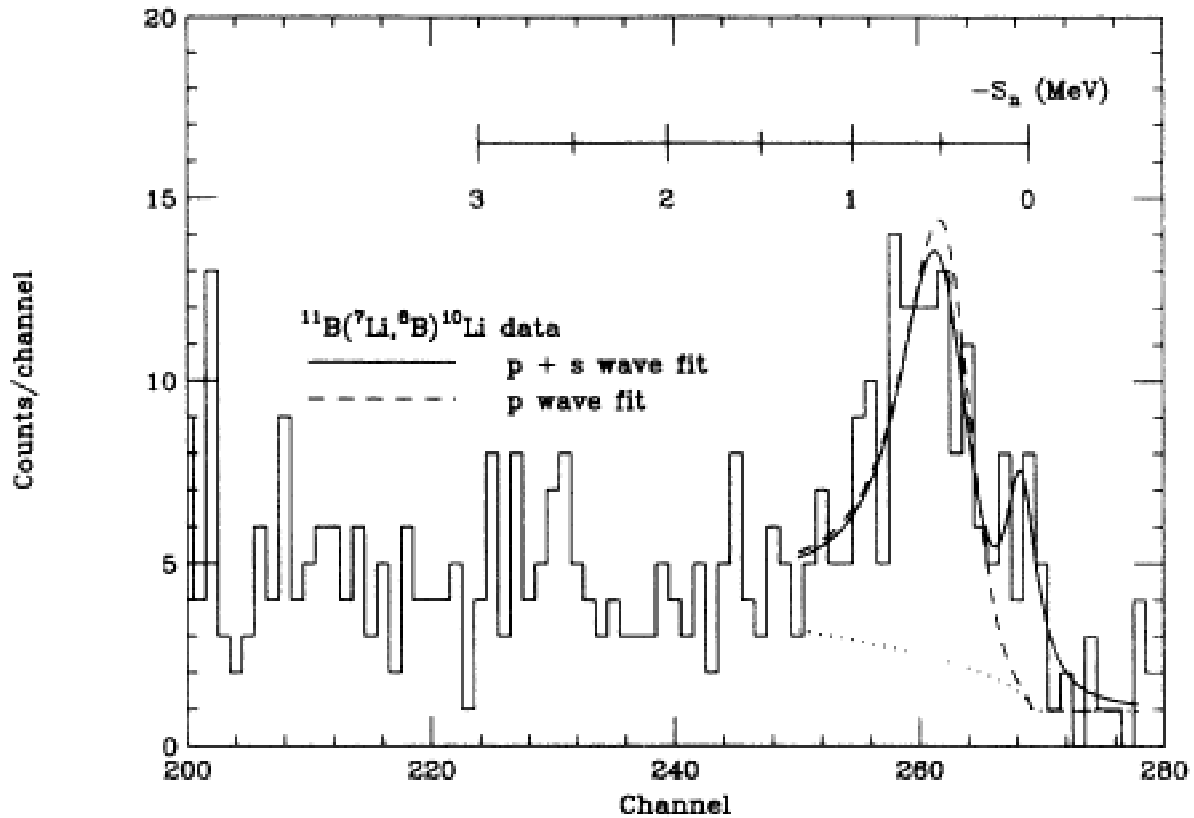
$$a_s = -\lim_{k \rightarrow 0} \frac{tan\delta_0}{k}$$

Where do we stand?…just an example…..

PHYSICAL REVIEW C VOLUME 49, NUMBER 1 JANUARY 1994

Low-lying structure of ^{10}Li in the reaction ^{11}B(^{7}Li,^{8}B)^{10}Li

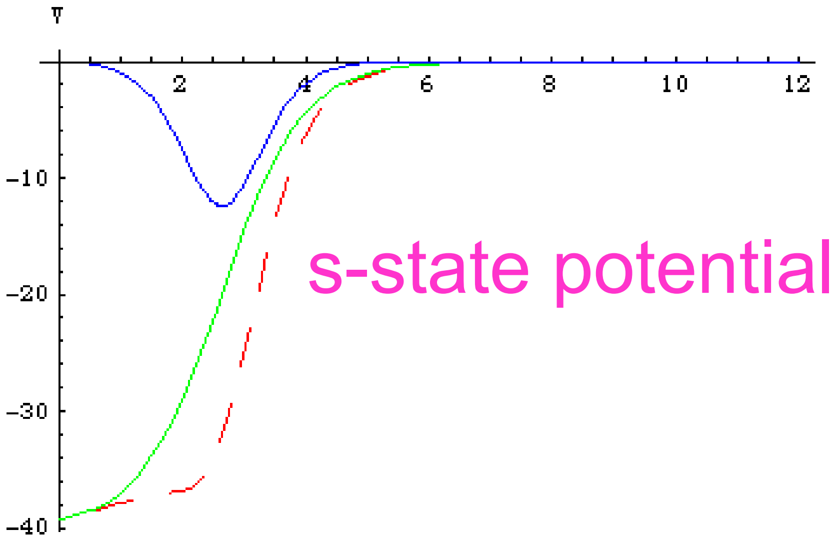
B. M. Young, W. Benenson, J. H. Kelley, N. A. Orr,* R. Pfaff, B. M. Sherrill, M. Steiner, M. Thoennessen, J. S. Winfield, J. A. Winger,† S. J. Yennello,† and A. Zeller
National Superconducting Cyclotron Laboratory and Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan 48824

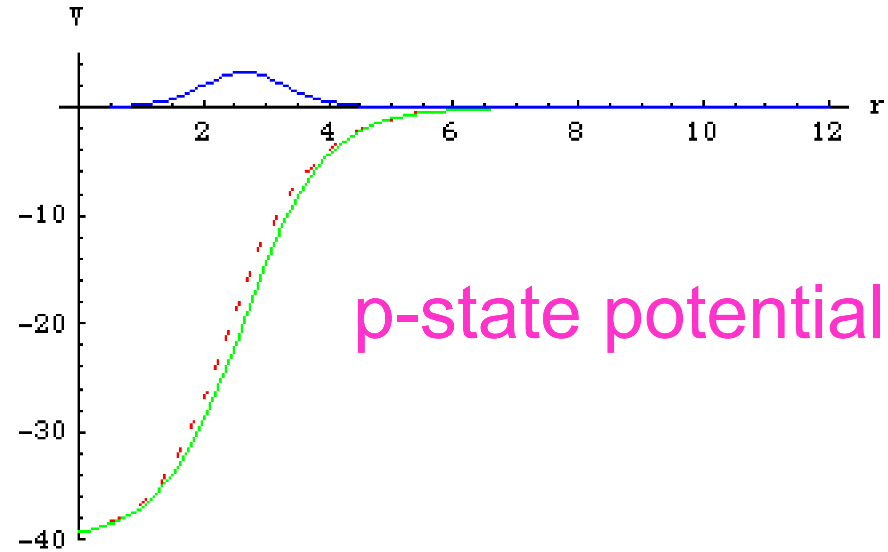


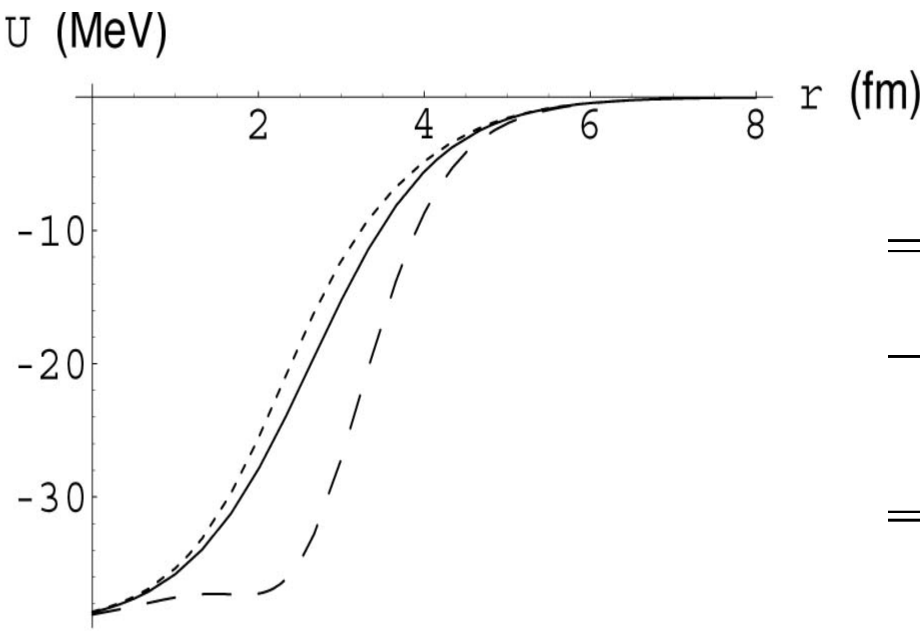
Potential model for n+^{9}Li continuum

$U(r) = V_{WS} + \alpha\, \delta V$

Woods-Saxon+surface-vibration coupling

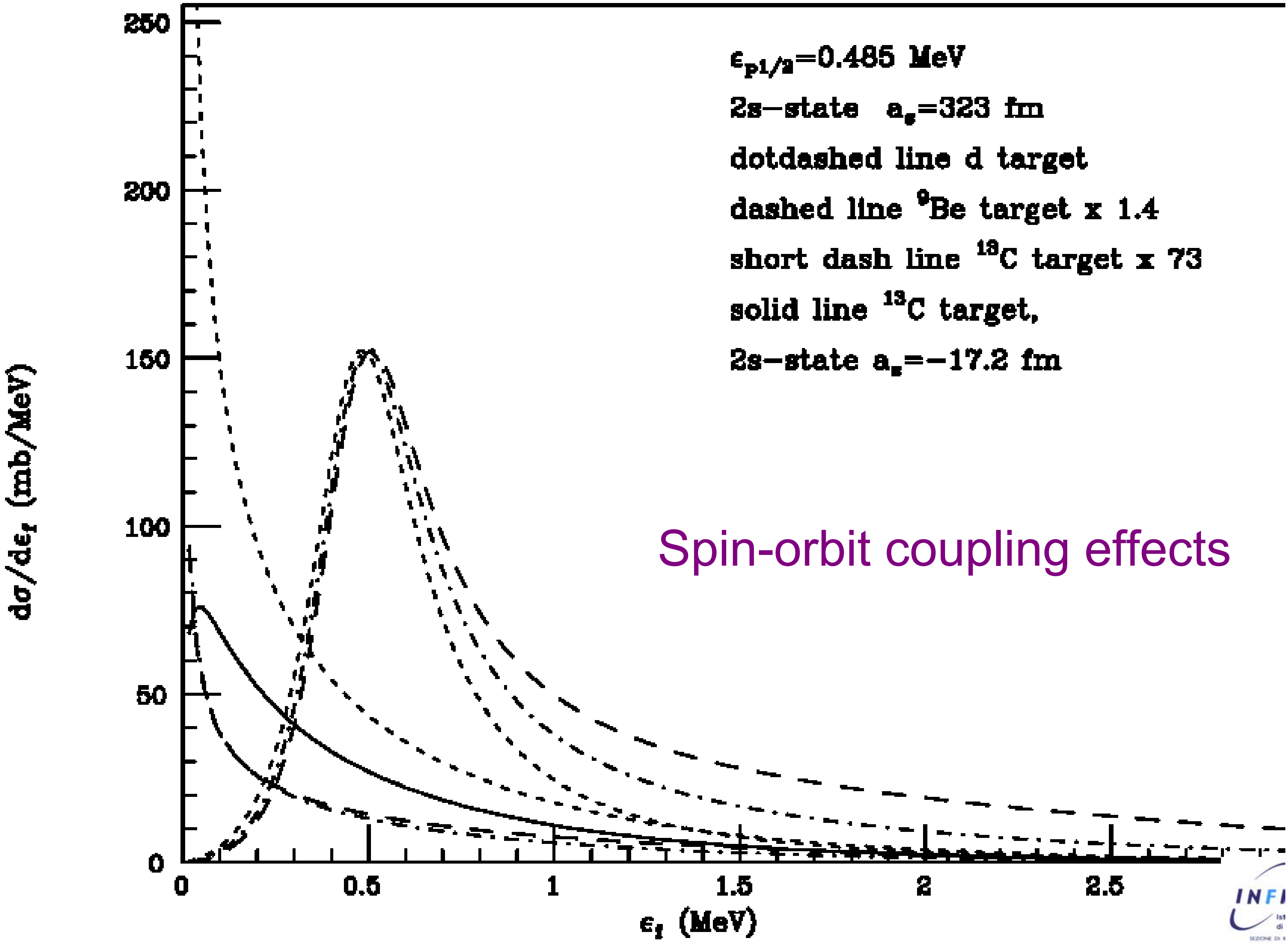




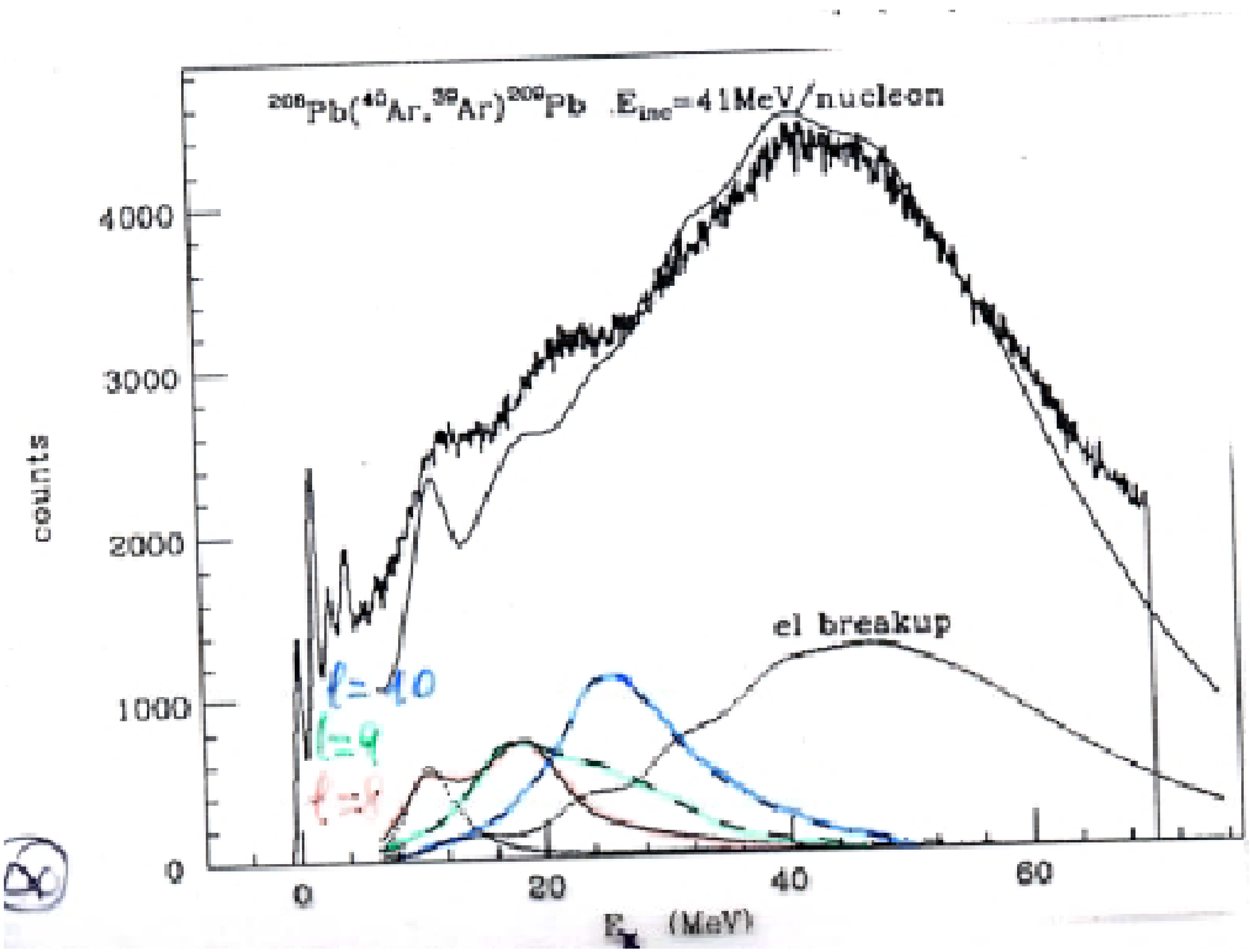


Resonance states in ^{10}Li

	ε_{res} (MeV)	Γ (MeV)	a_s (fm)	α (MeV)
$2s_{1/2}$			323	-12.5
			-17.20	-10.0
$1p_{1/2}$	0.595	0.48		3.3

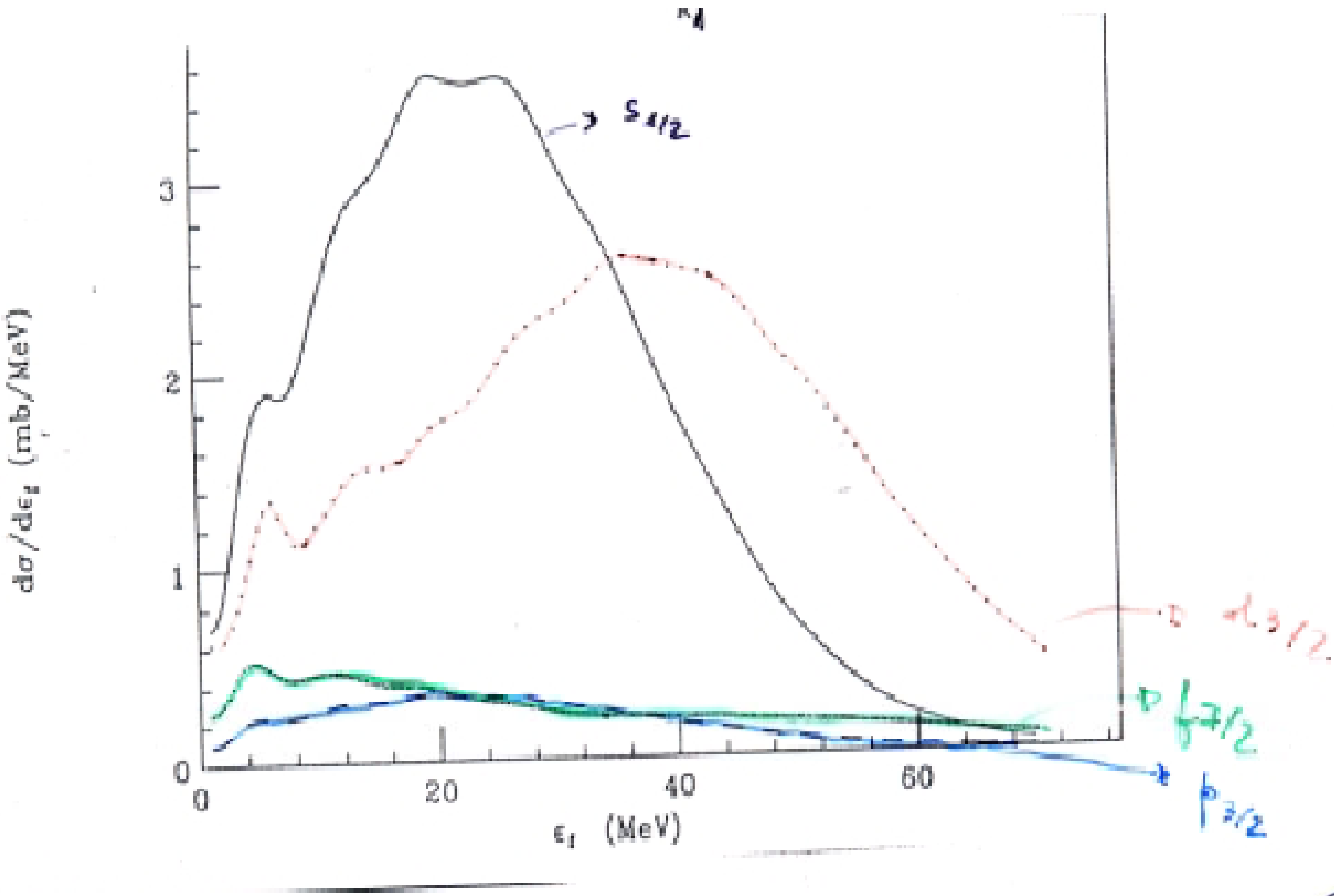


Spin-orbit coupling effects



Bonaccorso, Lhenry, Suomijarvi
PR C 49 (1994) 329

n-^{208}Pb Optical potential from Mahaux and Sartor NP A493 (1989) 157



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J of initial orbital determined by core momentum distributions.

A. B. and D.M. Brink, PRC44, 1559 (1991); PRC58, 2864 (1998), A.B,PRC60,546046

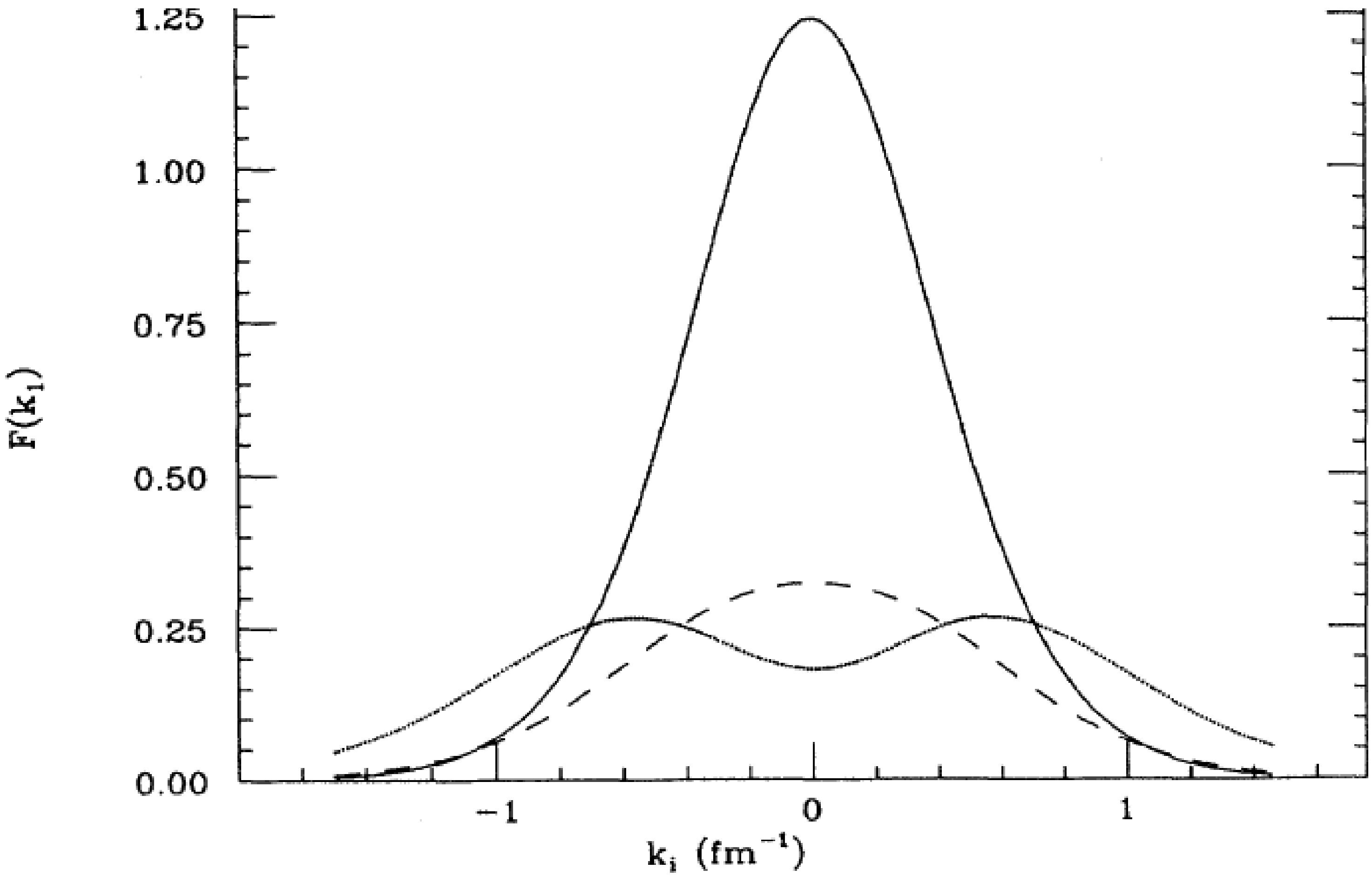

FIG. 11. Initial-state momentum distributions in ^{20}Ne according to Eq. (2.3a). The solid curve is for the $2s_{1/2}$ state, the dashed curve is the for $1p_{1/2}$, while the dotted curve is for the $1d_{5/2}$ state.

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Optical potentials of halo and weakly bound nuclei

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[25] R. A. Broglia, and A. Winther, *Heavy Ion Reactions*, Benjamin, Reading, Mass, 1981.

[26] R. A. Broglia, G. Pollarolo and A. Winther, Nucl. Phys. **A361**, 307 (1981).

[27] A. Bonaccorso, G. Piccolo, D. M. Brink, Nucl. Phys. **A441** (1985) 555.

[28] Fl. Stancu and D. M. Brink, Phys. Rev. C **32**, 1937 (1985).

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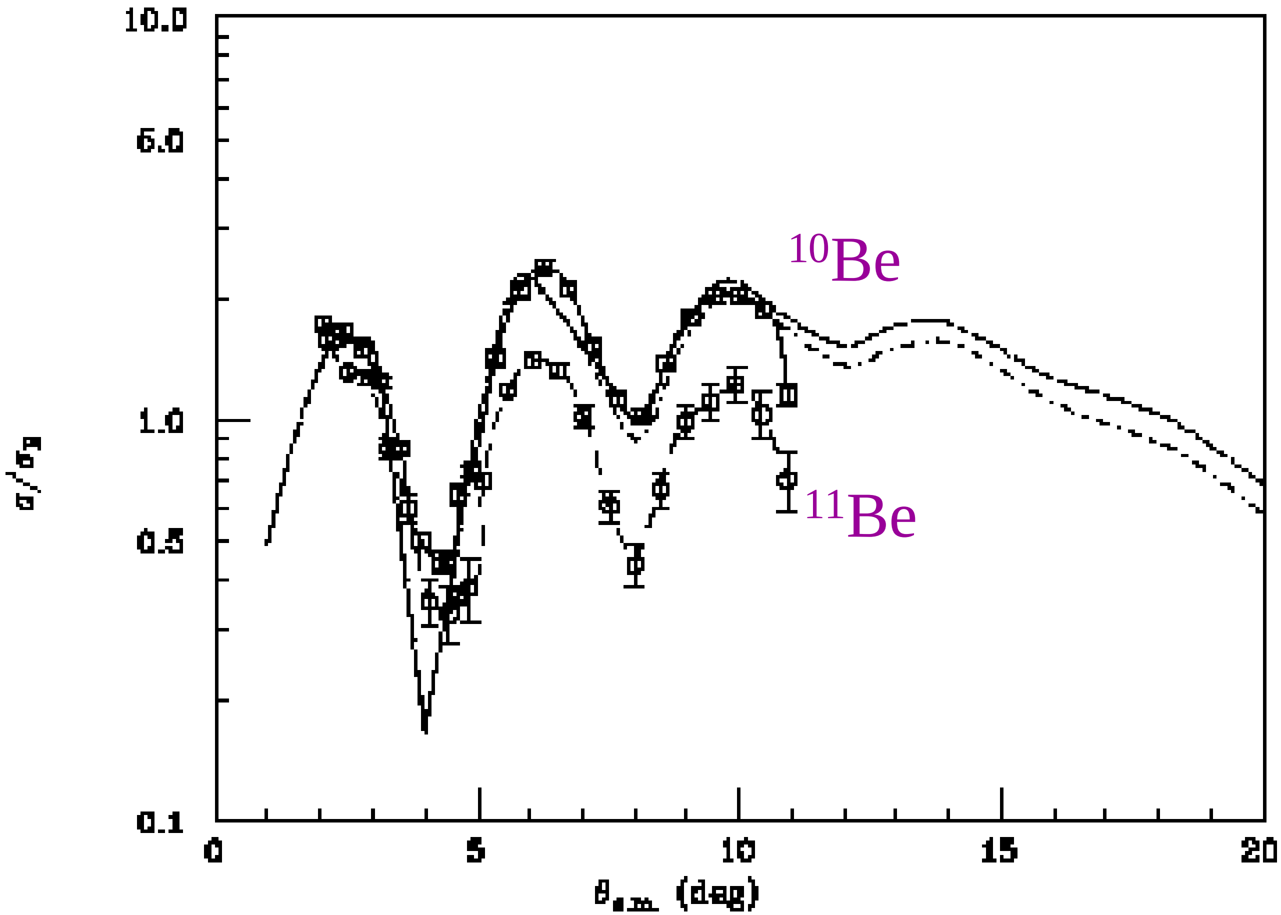
Elastic scattering and optical potential description select important reaction channels
Typical experiment to be done with EXCYT and MAGNEX going to large angles



GANIL data 49 A.MeV, P. Roussel-Chomaz et al., private communication.

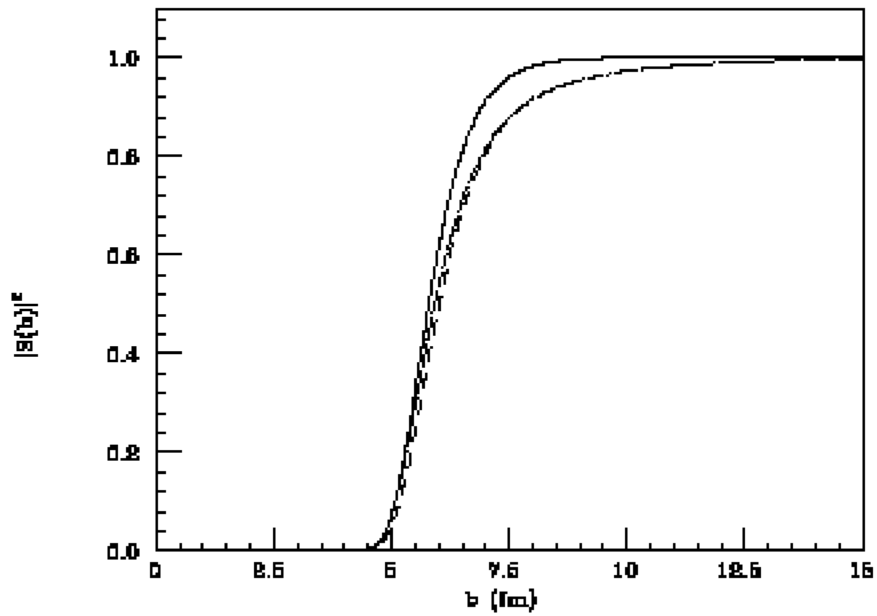


Figure 2: S-matrix values as a function of the impact parameter for the system $^{11}Be + ^{9}Be$ at 50A.MeV. Solid line is $|S_{CT}|^2$, dashed and dotted lines are $|S_{NN}|^2$ calculated with the two prescriptions for the breakup probability discussed in the text.

Optical potential from phase shift

$$|S_{NN}(b_c)|^2 = e^{-4\delta_I(b_c)}.$$

$$\delta_I(b_c) = -\frac{1}{2\hbar}\int_{-\infty}^{+\infty} \left(W_V(\mathbf{r}(t)) + W_S(\mathbf{r}(t))\right) dt$$

For each impact parameter

$$\int_{-\infty}^{+\infty} W_S(b_c z)dz = -\frac{\hbar v}{2} p_{b_{up}}(b_c) \qquad W_S(r) \approx W_0 e^{-\frac{r-R_S}{\alpha}}$$

where

$$W_0 \equiv W_0(R_s) = -\frac{\hbar v}{2} p_{b_{up}}(R_s) \frac{1}{\sqrt{2\pi\alpha R_s}}$$

$\eta \approx \gamma$
$\gamma = \sqrt{2mS_n}/ h$
$\alpha \approx 1/(2\gamma)$

$$
\begin{aligned}
1-|S_{NN}(b_c)|^2 &\approx 1-|S_{CT}(b_c)|^2 e^{-P_{b_{up}}(b_c)} \\
&= 1-|S_{CT}(b_c)|^2\left(1-P_{b_{up}}(b_c)\right) \\
&= 1-|S_{CT}(b_c)|^2+|S_{CT}(b)|^2 P_{b_{up}}(b_c)
\end{aligned}
$$

$$
\begin{aligned}
\sigma_{NN} &= 2\pi \int b_c db_c \left(1-|S_{NN}(b_c)|^2\right) \\
&\approx \sigma_{CT}+\sigma_{b_{up}}
\end{aligned}
$$

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